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LEVERAGING MONTE CARLO SIMULATION FOR PROJECT RISK MANAGEMENT: A STUDY ON PRE-MITIGATION AND POST-MITIGATION TECHNIQUES IN RISK REGISTERS

APROVECHAMIENTO DE LA SIMULACIÓN DE MONTE CARLO PARA LA GESTIÓN DE RIESGOS DE PROYECTOS: UN ESTUDIO SOBRE TÉCNICAS DE PREMITIGACIÓN Y POSTMITIGACIÓN EN REGISTROS DE RIESGOS

Benigno Alfredo Armijos De La Cruz
Universitat Politècnica de València – Spain

Jose Raul Castro Esparza
Universidad Autónoma de Zacatecas – Mexico

Jimmy Francisco Leoro Benitez
Universitat Politècnica de València - Spain

Wendy Yleana Armijos De La Cruz
Institute of Banking and Financial Practices - Ecuador

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Leveraging Monte Carlo Simulation for Project Risk Management: A Study on Pre-Mitigation and Post-Mitigation Techniques in Risk Registers

Benigno Alfredo Armijos De La Cruz[1]
baarmdel@upv.edu.es
https://orcid.org/0000-0003-4442-2697
Universitat Politècnica de València
Spain

Jose Raul Castro Esparza
jrcastroe@uaz.edu.mx
https://orcid.org/0000-0003-1443-7062
Universidad Autónoma de Zacatecas
Mexico

Jimmy Francisco Leoro Benitez
jfleoben@upv.edu.es
https://orcid.org/0009-0009-6670-0708
Universitat Politècnica de València
Spain

Wendy Yleana Armijos De La Cruz
wendyarmijos@ipbf.edu.ec
https://orcid.org/0000-0001-5518-8387
Institute of Banking and Financial Practices
Ecuador

ABSTRACT

This article focuses on the utilization of pre-mitigation and post-mitigation techniques in risk registers, employing Monte Carlo simulation, to enhance project risk management. Through a comprehensive literature review and analysis of a software project case study in a telecommunications equipment company, this research aims to quantify the benefits of integrating these techniques as part of their risk management process. The outcomes include quantitative assessments of pre-mitigation and post-mitigation techniques, as well as the identification of best practices and recommendations for their implementation using a business analytics tool based on Monte Carlo simulation. This research holds significance for project managers and organizations seeking to improve objectively risk management practices, ultimately leading to more successful project outcomes based on a probabilistic mindset.

Keywords: project, risk, pre-mitigation, post-mitigation, Montecarlo, simulation

[1] Autor principal
Correspondencia: baarmdel@upv.edu.es

Aprovechamiento de la Simulación de Monte Carlo para la Gestión de Riesgos de Proyectos: Un Estudio sobre Técnicas de Premitigación y Postmitigación en Registros de Riesgos

RESUMEN

Este artículo se enfoca sobre la utilización de técnicas de pre-mitigación y post-mitigación en registros de riesgos en proyectos, empleando la simulación de Monte Carlo, para mejorar la gestión de riesgos. A través de una exhaustiva revisión de literatura y análisis de un estudio de caso de un proyecto de software en una empresa de equipos de telecomunicaciones, esta investigación tiene como objetivo cuantificar los beneficios de integrar estas técnicas como parte de su proceso de gestión de riesgos. Los resultados incluyen evaluaciones cuantitativas de las técnicas de pre-mitigación y post-mitigación, así como la identificación de las mejores prácticas y recomendaciones para su implementación utilizando una herramienta de análisis empresarial basada en la simulación de Monte Carlo. Esta investigación tiene relevancia para los gestores de proyectos y las organizaciones que buscan mejorar las prácticas de gestión de riesgos de manera objetiva, lo que conduce a resultados exitosos basados en un enfoque probabilístico.

***Palabras clave*:** proyecto, riesgo, pre-mitigación, post-mitigación, Monte Carlo, simulación

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INTRODUCTION

Effective project risk management is crucial for organizations to achieve project success in an increasingly complex and uncertain business environment. Identifying, assessing, and mitigating risks are fundamental steps in the risk management process. Risk registers serve as valuable tools for capturing and documenting project risks, providing a foundation for informed decision-making and integrated risk management. Traditionally, risk registers have focused on identifying and assessing risks without incorporating comprehensive pre-mitigation and post-mitigation strategies. Nevertheless, advancements in risk management techniques, such as Monte Carlo simulation, present an opportunity to enhance the effectiveness of project risk management (Schatteman et al., 2008).

The organization of this article is as follows. A comprehensive review of existing literature on project risk management, pre-mitigation and post-mitigation techniques, and Monte Carlo simulation was conducted. Moreover, a project case study based on a telecom's equipment company was selected to collect data on the implementation of pre-mitigation and post-mitigation techniques in risk registers. Data was gathered on risk identification, assessment, and mitigation strategies employed throughout the project lifecycle. Thereafter, a simulation model was developed based on the collected data to simulate project risks and outcomes. Monte Carlo simulation techniques were applied to assess the uncertainty associated with identified risks and evaluate the effectiveness of pre-mitigation and post-mitigation techniques. Finally, the last section provides overall conclusions about the adoption of these techniques.

This article with methodological applications in the discipline of project risk management aims to contribute to the existing body of knowledge by providing empirical evidence and insights on the benefits of integrating pre-mitigation and post-mitigation techniques in risk registers using a simulation-based approach. It explores the following research questions:

- How effective are pre-mitigation techniques in project risk registers using Monte Carlo simulation?
- What is the impact of post-mitigation techniques on project risk registers through Monte Carlo simulation?
- What are the pros and drawbacks of implementing pre-mitigation and post-mitigation techniques for minimizing the impact of risks on project objectives?

Pre-mitigation and post-mitigation techniques

Pre-mitigation techniques are a valuable tool for reducing the risk of project failure. By implementing pre-mitigation techniques, project managers can reduce the probability of risks occurring, and they can also reduce the impact of risks that do occur (Aarthipriya et al., 2008). Moreover, project managers can proactively identify and address potential risks before they materialize. This allows for the implementation of preventive measures to reduce the likelihood or impact of risks. Pre-mitigation techniques enable project teams to be prepared and better equipped to handle potential challenges, resulting in a higher probability of project success (Song & Vanhoucke, 2025)

On the other hand, post-mitigation techniques are those that are implemented after a risky event has occurred and are a valuable tool for reducing the risk of project failure. Despite careful planning, some risks may still materialize during project execution. By having strategies in place to address risks as they occur, project managers can minimize their impact on project objectives. Post-mitigation techniques enable agile and adaptive responses to emerging risks, allowing project teams to navigate unforeseen circumstances and maintain project progress.

Overall, the adoption of both pre-mitigation and post-mitigation techniques ensures a comprehensive approach to risk management. It enables project managers to anticipate and mitigate potential risks proactively while also responding effectively to risks that materialize. This comprehensive risk management approach enhances decision-making, resource allocation, and ultimately leads to improved project outcomes. The adoption of pre-mitigation and post-mitigation techniques in risk registers is crucial for effective project risk management. According to Salah & Moselhi (2014), here are the reasons why their adoption is necessary:

- Proactive risk management: Pre-mitigation techniques allow project managers to take proactive measures to identify and address potential risks before they occur (Cuadros & Ramirez, 2024). By anticipating and addressing risks early on, project teams can reduce the likelihood or impact of those risks, ensuring smoother project execution. In the same vein, post-mitigation techniques provide an opportunity to analyze the implementation of preventive strategies, such as risk avoidance or risk reduction measures, to minimize the occurrence of risks and their potential negative consequences (Starczyk & Jędras, 2025).

- Risk reduction and mitigation: Even with careful planning, some risks may still materialize during project execution. This is where post-mitigation techniques come into play. By having post-mitigation strategies in place, project managers can effectively manage and mitigate risks as they arise. These strategies enable project teams to respond swiftly and efficiently to address the impacts of risks, minimizing disruptions and reducing project delays or failures. Pre and post-mitigation techniques provide an agile approach to risk management, allowing for adaptive responses in real-time (Ichsan et al., 2025).
- Optimal resource allocation: The adoption of pre-mitigation and post-mitigation techniques helps project managers allocate resources optimally. With pre-mitigation techniques, resources can be allocated proactively to address potential risks, ensuring that the necessary measures and controls are in place (Moselhi & Roghabadi, 2020). Post-mitigation techniques allow for efficient resource utilization in managing unforeseen risks, preventing wastage and ensuring that resources are directed to the most critical areas of concern (Hadad & Keren, 2025).
- Improved project outcomes: By integrating pre-mitigation and post-mitigation techniques into risk registers, project managers can significantly enhance project outcomes. Proactive risk management minimizes the occurrence of risks and associated disruptions, increasing the likelihood of project success (Platon & Constantinescu, 2014). Additionally, effective post-mitigation strategies reduce the negative impacts of risks when they do occur, mitigating potential setbacks and maintaining project progress (Saiz et al., 2024).

Monte Carlo simulation in risk management

Monte Carlo simulation is a statistical technique that can be used to analyze the probability of different outcomes for a project. By running multiple simulations, Monte Carlo simulation can help to identify the most likely outcome for a project, as well as the range of possible outcomes. This technique can be used to analyze the effectiveness of pre-mitigation and post-mitigation techniques in risk registers. For instance, a project manager could use Monte Carlo simulation to compare the results of a project with and without pre-mitigation techniques (Ievlanov, 2025). The results of the simulation could then be used to determine the effectiveness of the pre-mitigation as well as post-mitigation techniques (Ottaviani et al., 2024).

Furthermore, the utilization of Monte Carlo simulation in risk registers provides a quantitative framework for analyzing and managing project risks (Senova et al., 2019). By generating probabilistic outcomes through iterative simulations, project managers can better understand the potential impacts of risks and assess the effectiveness of mitigation strategies. This approach enables more informed decision-making and allocation of resources to mitigate risks effectively (Hojjati & Noudehi, 2015). There is a growing body of literature on the use of Monte Carlo simulation in project risk management. Several studies have shown that Monte Carlo simulation can be a valuable tool for identifying and assessing risks, as well as for developing mitigation strategies (Senses & Kumral, 2024).

The adoption of Monte Carlo simulation in project risk management, particularly in risk registers, is necessary due to several compelling reasons:

- Probabilistic risk analysis: Traditional risk management techniques often rely on deterministic approaches, considering only single-point estimates for risk factors (Wali & Othman, 2019). Nonetheless project risks are characterized by inherent uncertainty and variability. Monte Carlo simulation allows for probabilistic analysis by incorporating probabilistic distributions for risk variables (Shavyrina & Liberzon, 2021). This provides a more realistic representation of uncertainty, enabling project managers to better understand the range of possible outcomes and make informed decisions.
- Quantitative risk evaluation: Monte Carlo simulation facilitates quantitative risk assessment by generating several simulated scenarios based on probability distributions (Torres-Barboza & Longo, 2018). This simulation-based approach allows project managers to quantify the likelihood and impact of risks and uncertainties, providing valuable insights into their potential effects on project objectives. By quantifying risks, project managers can allocate resources effectively, and develop contingency plans (Ho et al., 2019).
- Comprehensive risk modeling: Risk registers serve as repositories of project risks, documenting their likelihood, impact, and mitigation strategies. Monte Carlo simulation enhances risk modeling in registers by allowing for the consideration of multiple interconnected risk factors (Wu, 2025). The simulation accounts for correlations and dependencies among risks, capturing their collective

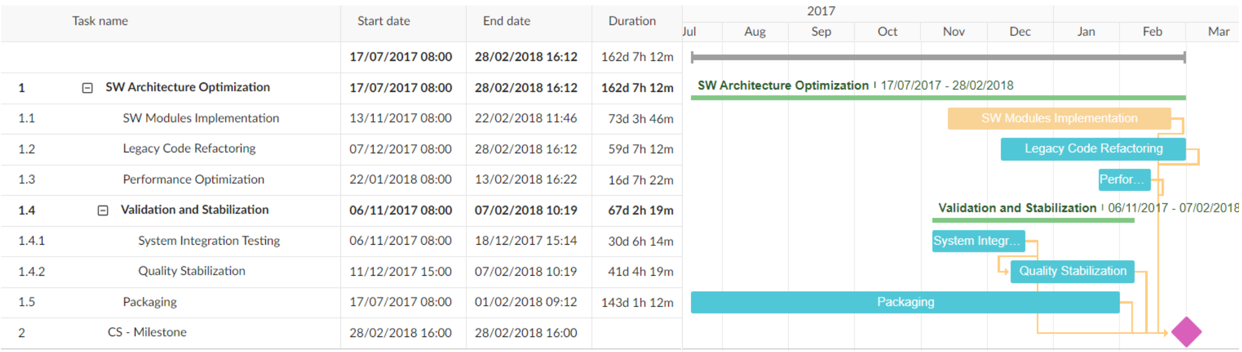
impact on project outcomes. This comprehensive modeling capability enables a more accurate assessment of overall project risk exposure. (Damnjanovic et al., 2020)

- Sensitivity risk analysis: Monte Carlo simulation enables sensitivity analysis by assessing the sensitivity of project outcomes to different risk variables. Project managers can identify the most influential risks or input variables that significantly affect project performance. By understanding these sensitivities, decision-makers can prioritize risk mitigation efforts and focus resources on critical areas, improving the effectiveness of risk management strategies (Sobiera & Metelski., 2022).

Methodology and data collection

Extensive literature was examined to ascertain the methods of risk identification, and diverse techniques were evaluated to address and minimize potential risks (Kumar, 2022). The project case study was developed in a telecom's equipment company based on a critical software architecture optimization as part of its project portfolio. It consisted of software modules implementation, legacy code refactoring and performance optimization as part of the first stage of the project. Finally, project tasks such as system integration testing and quality stabilization are developed, including packaging as its last stage. Bearing in mind all that project data, the project schedule and its Gantt chart was detailed in Figure 1:

Figure 1. Project schedule and deterministic Gantt chart



Through interviews and focus groups, the examination of a risk register and its influence on time and cost was conducted (Alves Cantini et al., 2022). The analysis encompassed various identified risks. Regarding time, evaluations including quantitative risk analysis, such as Monte Carlo simulation, and sensitivity analysis were performed and analyzed utilizing the software solution Schedule Risk Analysis (SRA) embedded in @RISK, an add-in tool which combines key features of Microsoft Excel and

Microsoft Project platforms. As part of the quantitative risk methodology, the first step in the import process is selecting the schedule file. @RISK SRA opens the selected file and reads the tasks and resource information from the schedule. It then builds the model Excel worksheet. The imported project schedule and risk register file was shown in Figure 2 and Table 1.

Figure 2. Project schedule imported in @RISK - Schedule Risk Analysis

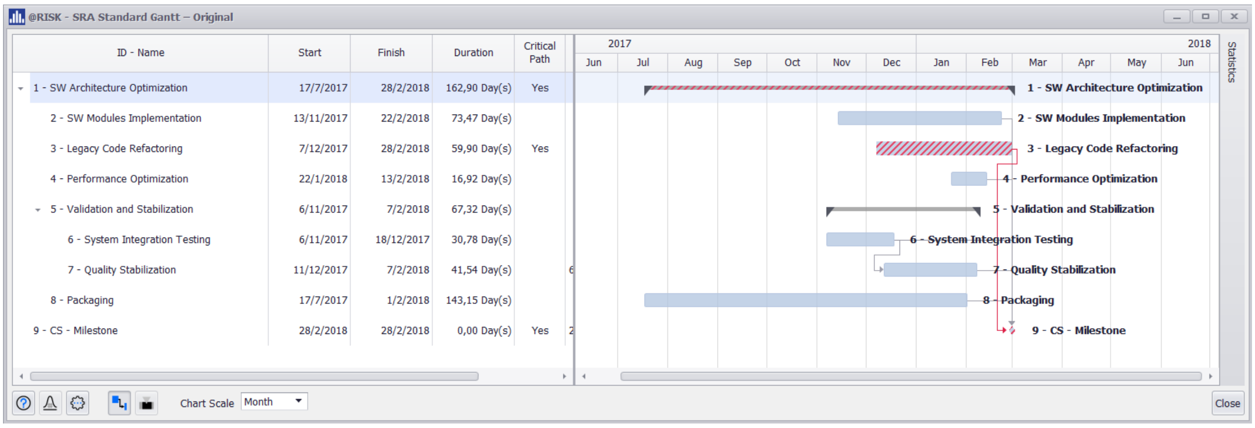


Table 1. Project risk register imported in @RISK - Schedule Risk Analysis

Qualitative Analysis						
Risks Identification				Deterministic Analysis		
Risk ID	Risk Name	Risk Impact description	Mitigation tasks	Severity in Days (Most Likely)	Probability	Risk Rank
RSK-1	New features feasibility research might not have been sufficient	BT FW updates might be required late on, which pushed char runs beyond CS	Mitigation: Char results are reported weekly with RIOG and BT FW teams addressing issues as they are identified; several BT FW patches will be made available as we go along to address these different issues and therefore reduce the number of bugs as we approach CS	15,0000	0,3500	5,2500
RSK-2	The scope of Legacy Code Refactoring effort can be much bigger than expected	Development boards might fail emissions testing, redesign needed	Mitigation: Use lab boards & shrunk lab board design to do emissions testing and get initial results	20,0000	0,3600	7,2000
RSK-3	Not all interdependencies between the subsystems were considered	Program Cohabitation - Audio ClassD amplifier may desense BT Radio	Design has ability to control the Class D amp to reduce the affects on RF performance, e.g. modify slew rate, pcb layout, changing switching frequency	15,0000	0,3500	5,2500
RSK-4	Code Refactoring affects Performance and Quality	Program Cohabitation - BT affects Audio Performance/Quality	Review pcb design to ensure best known method is implemented to prevent such cross-talk	15,0000	0,3500	5,2500
RSK-5	Performance not meeting specification	Program Cohabitation - Aux macro Pin assignment may create spurs affecting BT Radio	Review pin assignment of AUX vs BT during package design & run simulations whenever possible	25,0000	0,5200	13,0000
RSK-6	Change can cause stability lavel to fall below acceptable level	Program Cohabitation - BT Radio desense from SMPS for small form factor designs	Review SMPS PWB design to ensure that best known method is implemented	25,0000	0,7200	18,0000

In the earlier deterministic risk analysis of this project, which considered the expected monetary value as a criterion (Mun, 2022), the combination of the likelihood of occurrence and the impact in terms of project schedule delay led to the identification of the most severe risks, namely RSK-5 and RSK-6. These risks were given priority in the development of response strategies as part of the qualitative risk analysis. The prioritization process involved using qualitative scales for assessing probability and impact, following the guidelines set by the Project Management Institute (PMI, 2014).

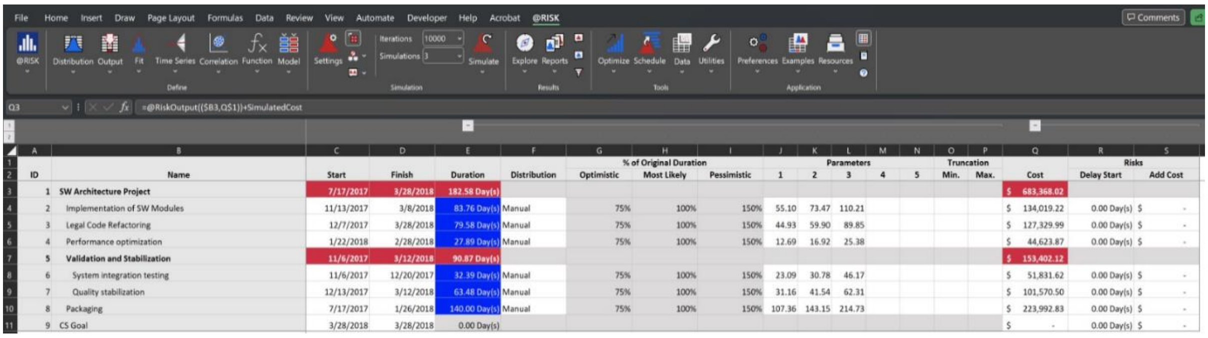
The aim of this work was to contrast a traditional qualitative risk analysis with a probabilistic risk approach considering a simulation-based approach to be shown in the following sections.

RESULTS AND DISCUSSION

This study focuses on the outcomes of risk analysis concerning their effects on project schedule and budget. Therefore, the original project duration, as well as the durations for pre-mitigation and post-mitigation scenarios, were determined using Monte Carlo simulation. Sensitivity analyses, employing tornado diagrams and probabilistic Gantt charts, were conducted to assess the schedule's sensitivity to different factors regarding uncertainty and impact of the project risk register on the project baseline.

Initially we need to associate probability distributions for each duration of the tasks, which are shown in Figure 3.

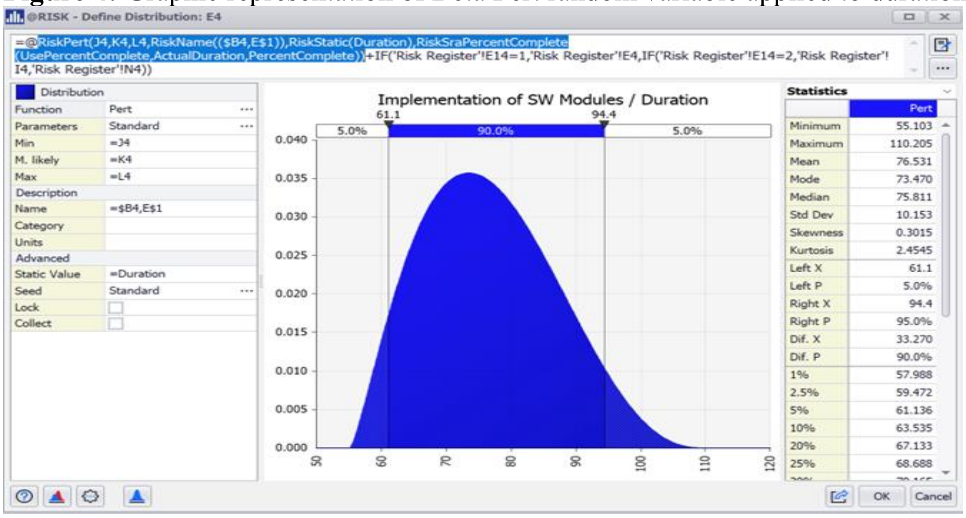
Figure 3. Probabilistic representation of project variables with @RISK



ID	Name	Start	Finish	Duration	Distribution	Optimistic (% of Original Duration)	Most Likely	Pessimistic	Parameters 1	2	3	4	5	Truncation Min.	Max.	Cost	Risks Delay Start	Add Cost
1	SW Architecture Project	7/17/2017	3/28/2018	182.58 Day(s)												$ 683,368.02		
2	Implementation of SW Modules	11/13/2017	3/8/2018	83.76 Day(s)	Manual	75%	100%	150%	55.10	73.47	110.21					$ 134,019.22	0.00 Day(s)	$ -
3	Legal Code Refactoring	12/7/2017	3/28/2018	79.58 Day(s)	Manual	75%	100%	150%	44.93	59.90	89.85					$ 127,329.99	0.00 Day(s)	$ -
4	Performance optimization	1/22/2018	2/28/2018	27.89 Day(s)	Manual	75%	100%	150%	12.69	16.92	25.38					$ 44,623.87	0.00 Day(s)	$ -
5	Validation and Stabilization	11/6/2017	3/12/2018	90.87 Day(s)												$ 153,402.12		
6	System integration testing	11/6/2017	12/20/2017	32.39 Day(s)	Manual	75%	100%	150%	23.09	30.78	46.17					$ 51,831.62	0.00 Day(s)	$ -
7	Quality stabilization	12/13/2017	3/12/2018	63.48 Day(s)	Manual	75%	100%	150%	31.16	41.54	62.31					$ 101,570.50	0.00 Day(s)	$ -
8	Packaging	7/17/2017	1/26/2018	140.00 Day(s)	Manual	75%	100%	150%	107.36	143.15	214.73					$ 223,992.83	0.00 Day(s)	$ -
9	CS Goal	3/28/2018	3/28/2018	0.00 Day(s)												$ -	0.00 Day(s)	$ -

In most cases, a Beta Pert probability distribution is used whenever the project uses estimates of optimistic, most likely and pessimistic cases (also known as minimum, mode and maximum values). As an example, Figure 4 describes the variability associated to one of the tasks in terms of its duration.

Figure 4: Graphic representation of Beta Pert random variable applied to duration.



Furthermore, measures for mitigating time and cost overruns were considered as could be shown in Table 2.

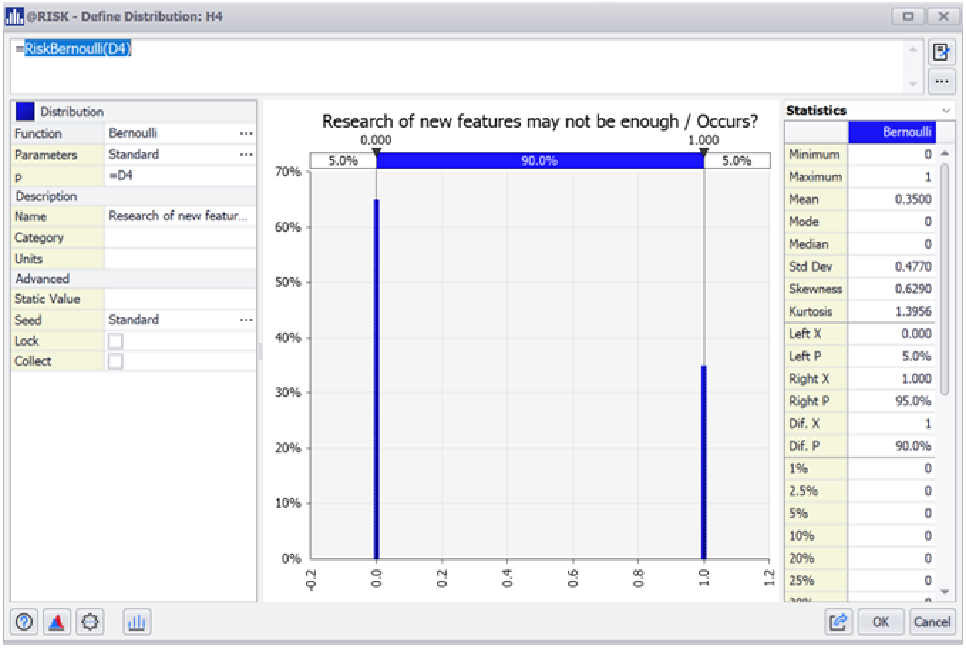
Table 2. Pre and post-mitigation strategies analysis results

Risk Identification		Deterministic Analysis			Probabilistic Analysis Pre-Mitigation				Probabilistic Analysis Post-Mitigation				
Risk ID	Risk name	Severity in days (Most likely)	Probability	Expected value	Severity in days	Probability	Occurs?	Risk impact	Mitigation cost (Days)	Severity (Days)	Probability (Reduced)	Occurs?	Risk impact
RSK-1	Research of new features may not be enough	15	0.35	5.25	16.61	35.0%	0	0.00	2	11.21	17.5%	0	0.00
RSK-2	The scope of the refactoring legacy code may be larger than expected.	20	0.36	7.2	24.09	36.0%	0	0.00	1	21.88	18.0%	1	21.88
RSK-3	Not all system interdependencies were considered.	15	0.35	5.25	14.28	35.0%	0	0.00	2	18.74	17.5%	0	0.00
RSK-4	Refactoring code affects performance and quality	15	0.35	5.25	9.73	35.0%	0	0.00	1	13.10	17.5%	0	0.00
RSK-5	Performance does not meet specifications	25	0.52	13	23.50	52.0%	1	23.50	1	23.67	26.0%	1	23.67
RSK-6	Change may cause stability to drop to an unacceptable level	25	0.72	18	26.16	72.0%	1	26.16	1	20.13	36.0%	1	20.13

Impacto global de riesgos					
Deterministic (Option 1)	53.95	Pre-Mitigation (Option 2)	49.67	Post-Mitigation (Option 3)	65.69
Opción Simulada	1				

The probability distribution functions used to describe frequency (occurrence) could either be Bernoulli or Binomial, as they are often applied to simulate two possible outcomes: Success (given as 0) or failure (given as 1). Figure 5 shows an example of this type of distribution to model a risk.

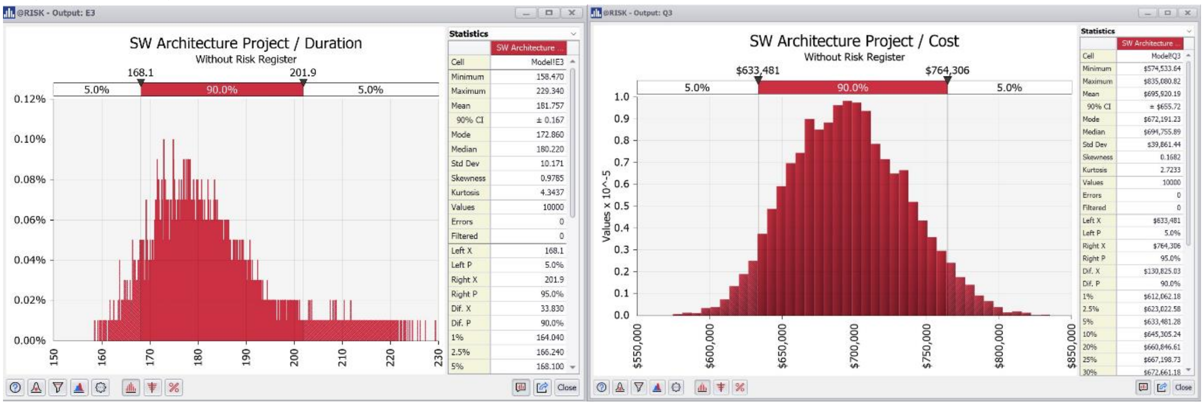
Figure 5. Graphic representation of Bernoulli probability function applied to risk occurrence.



Upon the conclusion of the analysis, consisting of 10,000 iterations conducted using @RISK Schedule Risk Analysis, Figure 6 depicts the histogram illustrating the overall project duration and cost in the absence of risks outlined in the risk register. Based on a 95% probability level, it is estimated that the project duration would not exceed 202 days, accompanied by a total cost of less than $764,306.

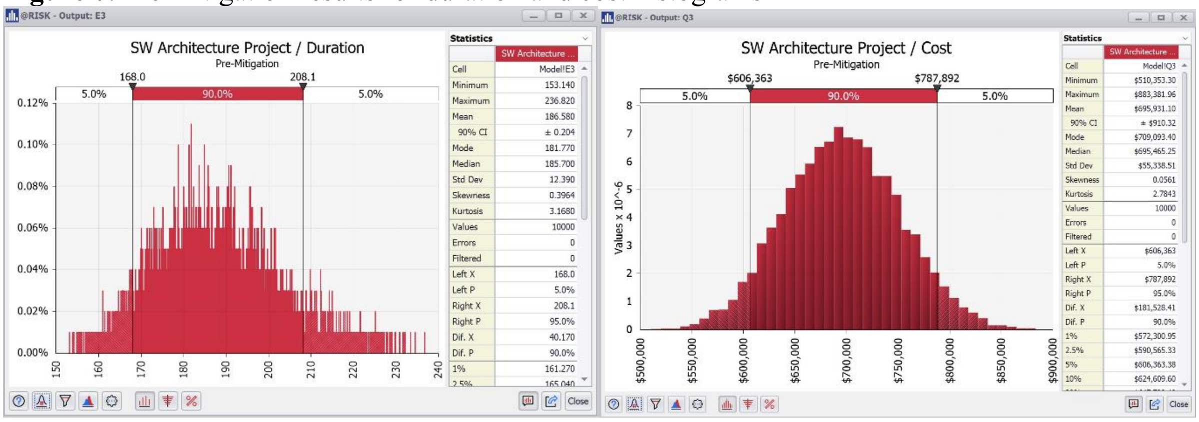
A confidence interval of 90% indicates an anticipated project duration ranging from 168,1 to 201,9 days, while the expected project budget falls within the range of $633,481 to $764,306.

Figure 6. Original planned duration and cost histograms



In addition to the aforementioned findings, an analysis was conducted to assess the impact of the risk register on the project through pre-mitigation strategies. The results of this analysis are illustrated in Figure 7, showcasing the outcomes for both time and cost project constraints. Based on a 95% probability level, it is projected that the project duration will not exceed 209 days, with a total cost amounting to less than $787,892. Within a 90% confidence interval, the expected project duration falls within the range of 168 to 208 days, while the projected project budget is estimated to range between $606,363 and $787,892.

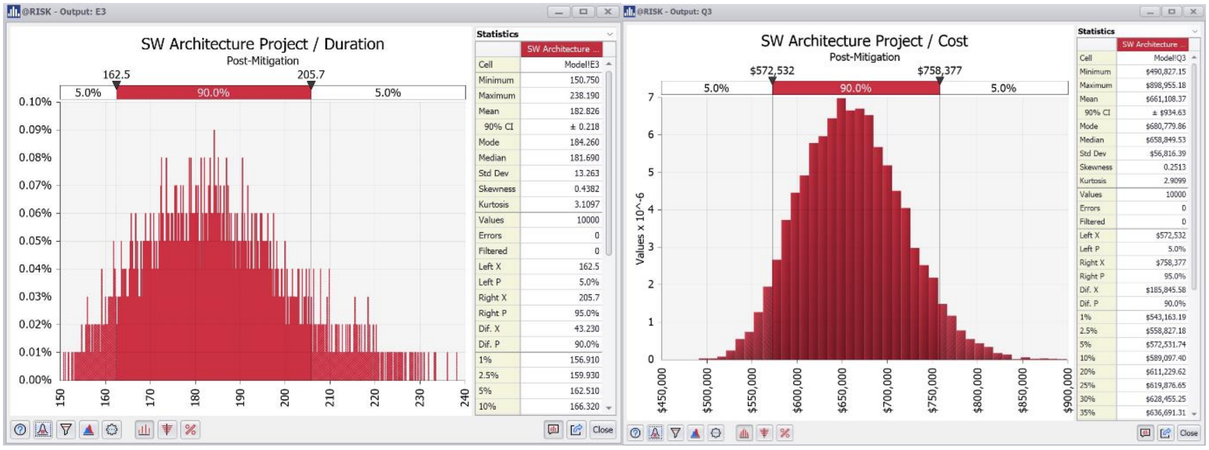
Figure 7. Pre-mitigation results for duration and cost histograms



Alternatively, to evaluate the effectiveness of risk responses implemented for each identified risk, a post-mitigation analysis was conducted, revealing a notable reduction in delays and cost overruns. Figure 8 illustrates that, at a 95% probability level, the total project duration is estimated to be below 205,7 days, accompanied by a total cost less than $758,377, taking into account the comprehensive impact of all identified risks on the project baseline.

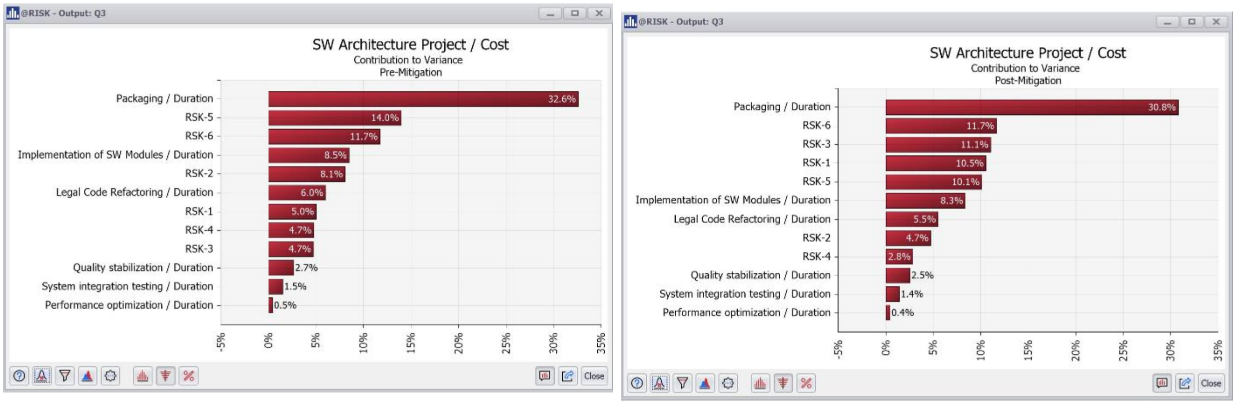
Descriptive statistics depict the benefits of these risk responses, affirming that the efforts invested in pre-mitigation and post-mitigation strategies prove to be an efficient approach compared to disregarding the potential effects of risks on the project.

Figure 8. Post-mitigation results for finish date and cost histograms



Furthermore, a sensitivity analysis was performed utilizing tornado diagrams. The purpose of the sensitivity analysis was to identify tasks and risks that hold the greatest potential impact on the project duration. Figure 9 illustrates all the tornado diagrams obtained during the simulation, highlighting that risks RSK-5 and RSK-6 have the most substantial influence on the overall project schedule taking into account the pre-mitigation scenario, with a 14% and 11,7%.

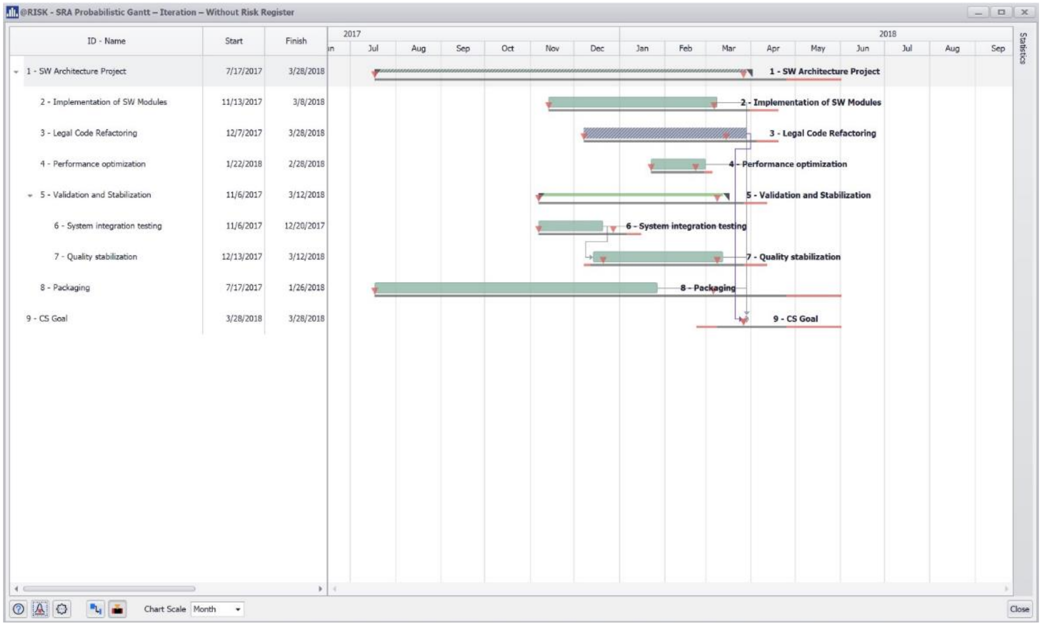
Figure 10. Pre and post-mitigation sensitivity tornado diagrams



Considering the preceding outcomes, it is now necessary to examine the implications of uncertainty and risks on the project. To accomplish this, a probabilistic Gantt chart becomes indispensable. This novel diagram of the conventional Gantt chart utilizes simulation data to present the potential fluctuations in durations and dates. By visually representing the simulated progression of the project over time, it allows for a comprehensive understanding of the possible schedule outcomes.

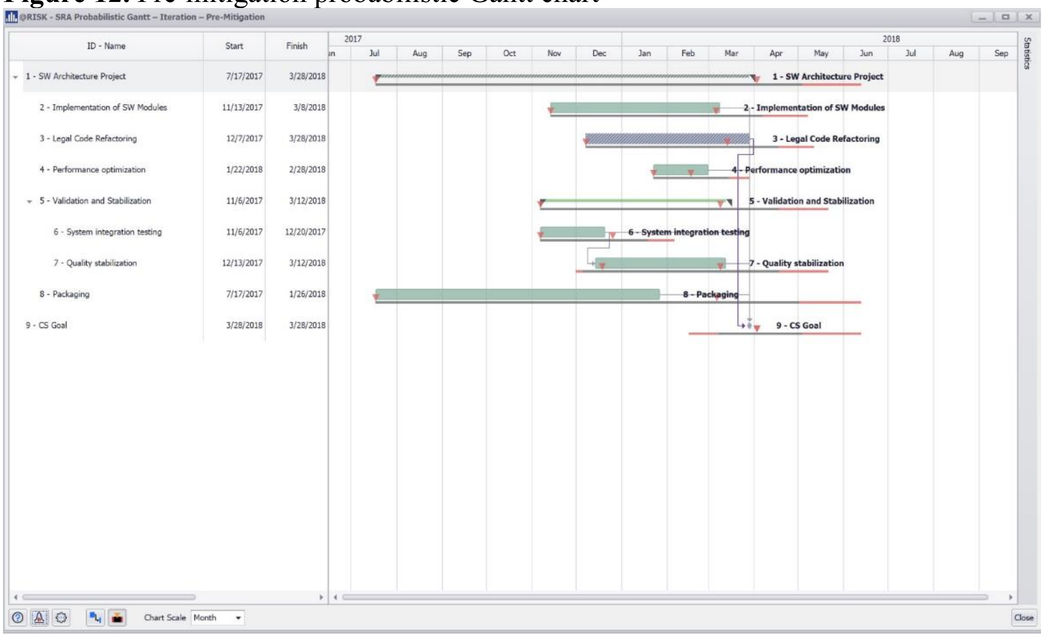
In the probabilistic Gantt chart, which does not consider the influence of a risk register, the projected completion time falls towards the end of May 2018. This projection considers the possibility of tasks starting either earlier or later than anticipated in the deterministic project schedule, as illustrated in Figure 11.

Figure 11. Original schedule probabilistic Gantt chart



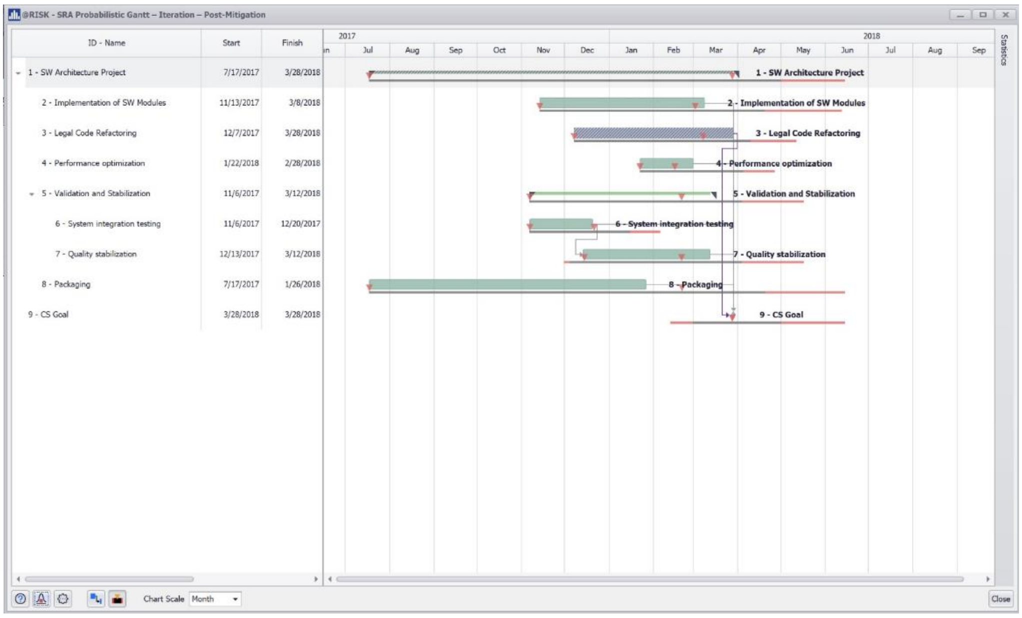
When taking into consideration additional risks listed in the risk register table, the projected finish time of the project is extended, resulting in completion by the middle of June 2018. This represents a two-week delay compared to the original timeline, as indicated in Figure 12.

Figure 12. Pre-mitigation probabilistic Gantt chart



Finally, Figure 13 presents a visual representation indicating that despite the inclusion of extra time to address risk mitigation, the decreased probabilities of external events occurring do not influence the overall timeline for project completion. The project is still expected to conclude by the middle of June, in accordance with the initial plan. Nevertheless, it is worth noting that the post-mitigation strategies implemented effectively contributed to reducing the additional costs associated with taking no action to mitigate the severity of all risks present in this project.

Figure 13. Post-mitigation probabilistic Gantt chart



To sum up this section, the implementation of a user-friendly risk assessment method and risk database that offers time and cost savings can effectively encourage telecom project teams to embrace a more quantitative approach to risk management. This approach allows for the reuse of past risk assessments, eliminating the need for repetitive and time-consuming efforts as well as reducing the bias derived from traditional project risk analysis. Prior to incorporating the pre-and post-mitigation estimating approach within the risk management process using Monte Carlo simulation, it is essential to carefully evaluate the potential advantages it offers in comparison to any potential challenges or drawbacks it may pose.

CONCLUSIONS

Project risk management involves the process of identifying, evaluating, and prioritizing risks, followed by the allocation of resources in a cost-effective manner to minimize, monitor, and control the likelihood or consequences of adverse events.

The incorporation of pre and post-mitigation techniques into project risk registers, specifically regarding schedule and budget analysis, presents significant challenges for telecommunications equipment companies. This article presents an effective quantitative risk management approach utilizing Monte Carlo simulation and a comprehensive set of qualitative and quantitative factors.

The method introduced enables the estimation of contingency reserves for both pre and post-mitigation scenarios, considering the cost and effectiveness of each mitigation strategy. The provided project case example demonstrates the capability of the proposed method in assessing the impact of risks on time and cost. Moreover, it highlights the method's practical application in cost-saving by estimating and allocating contingency reserves at the individual risk level. This approach enhances project managers' control over reserve utilization and reallocation. The example effectively highlights the applicability and benefits of the proposed method.

Moreover, this research focuses on identifying and analyzing risks, particularly their impact on project time and cost. To assess the impact on these traditional project restrictions, a quantitative risk analysis was conducted using the @RISK Schedule Risk Analysis software. This analysis involved utilizing Monte Carlo simulations, tornado diagrams, and probabilistic Gantt charts to evaluate schedule and budget sensitivity. Consequently, this aids project managers and companies in managing risks effectively and preventing potential delays and cost overruns in their projects, migrating from a deterministic risk framework into a probabilistic risk analytics approach.

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